ChemTalk

THE NUCLEUS OF AN ATOM

Discovery of the Neutron

The average atomic masses of some elements were known in Mendeleev's time, even though scientists didn't know much about the actual structure of an atom. In **Part A** of this activity you explored the idea of how the atomic mass relates to the atomic number. Mendeleev began organizing his periodic table by listing all the known elements in order of atomic mass. However, he found that organizing the elements in this way did not always make sense in terms of the behavior of the elements. He concluded that his measurements of atomic mass were incorrect and in those situations used the properties of the elements to place them in the table.

As it turned out, Mendeleev's measurements were not necessarily flawed. Although early models of the nucleus included the **proton**, the proton alone could not account for the fact that the mass of a helium atom is four times the mass of a hydrogen atom while the electric charge on the helium nucleus is only twice that of the hydrogen atom. Lord Rutherford (after discovering that atoms had a nucleus) addressed this problem when he suggested that another particle was present in the nucleus, with about the same mass as the proton but no electric charge. He named this particle the **neutron**.

Chem Words

proton: a positively charged subatomic particle contained in the nucleus of an atom. The mass of a proton is 1.673×10^{-24}g and has a charge of +1.

neutron: neutral subatomic particle with a mass of 1.675×10^{-24}g located in the nuclei of the atom.

The neutron was actually discovered in 1932 (by Chadwick, a British physicist), adding a great deal to the understanding of the nucleus of the atom. This discovery did not solve all of the mysteries concerning the atomic masses of some elements. Scientists today refer to protons and neutrons as nucleons since they reside in the nucleus and are almost identical in mass. The mass number tells us the number of nucleons.

Isotopes

In **Part A** of this activity you also investigated why the atomic mass of an element is not a whole number. Not all atoms of a given element have the same number of neutrons in the nucleus. Only the number of protons, the atomic number, is the same in all atoms of a given element. Atoms of the same element with different number of

neutrons in the nucleus are known as **isotopes** (meaning "same number of protons"). Isotopes are identified by their mass number, the sum of the number of neutrons plus protons.

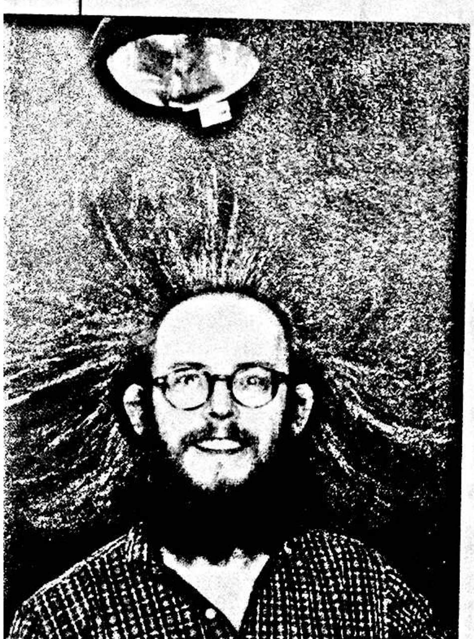
Chem Words

isotope: atoms of the same element but different atomic masses due to different number of neutrons.

You can refer to an element by its name (chlorine), by its atomic symbol (Cl), or by its atomic number (17). All three identifications are equivalent and used interchangeably in chemistry. The same element can have a different number of neutrons in the nucleus. Chlorine, which must have 17 protons in the nucleus, can have 18 or 20 neutrons. Chlorine with 20 neutrons and chlorine with 18 neutrons are the isotopes of chlorine (^{35}Cl and ^{37}Cl).

Electrostatic and Nuclear Forces

In **Part B** of this activity, when you brought the two positive strips near each other, they experienced a repulsive force. This was true for two negative strips as well. When a positive and a negative strip were brought close together, the force was attractive. As you have heard, "opposites attract!"



Inside the nucleus, the protons are repelling one another. Every pair of protons has a repulsive force between them. The force is very large because the distances within the nucleus are very small. The nucleus is between 10,000 and 100,000 times smaller than the atom. The electrical force can be described mathematically.

$$F = \frac{kq_1q_2}{d^2}$$

where F is the force,

k is Coulomb's constant (a number = 9×10^9 N m^2/C^2),

q_1 and q_2 are the charges, and
d is the distance between the charges.

As the distance between the charges increases the force weakens. Since the distance in the denominator is squared, if the distance triples the electrical force is 9 times (3^2) weaker or one-ninth as strong.

The question then becomes, what holds the protons together in the nucleus? The protons do have an electrical force pushing them apart but they have the larger nuclear force holding them together. The nuclear force is strong at short range. Anywhere beyond a distance of approximately 10^{-14} m (that's less than one 10 millionth of one 10 millionth of a meter), the nuclear force is zero. Neutrons in the nucleus are also attracted to each other and to protons with the nuclear force. Electrons are not affected by the nuclear force. Electrons belong to a different class of particles than protons and neutrons and do not interact with the strong nuclear force.

The nucleus is held together by a new force—the strong nuclear force. The nuclear force:

- is very, very strong at small distances;
- acts only between nucleons (proton-proton, proton-neutron, neutron-neutron);
- is always attractive;
- is very short range (if nucleons are more than 10^{-14} m apart, the nuclear force is zero).

The atom is held together by the electrostatic coulomb force. The electrostatic force:

- is strong at small distances, weak at large distances;
- acts only between charged particles (proton-proton, electron-electron, proton-electron);
- is attractive or repulsive;
- is long range (the force gets weaker at large distances).

All the nucleons are attracted by the nuclear force. The electrostatic force repelling protons in the nucleus is overwhelmed by the attractive nuclear force between these protons.

Unstable Atoms

You might expect to find nuclei of atoms with all sorts of combinations of neutrons and protons. Yet the quantity of isotopes for each element is rather small, and the number of elements is also limited. Moreover, elements do not occur in nature with atomic number greater than 92, and the highest atomic number for an atom created in the laboratory is 117.

There are two stable masses of chlorine, chlorine-35 and chlorine-37. The key word in this statement is "stable." There are other isotopes of chlorine, both heavier and lighter than chlorine-35 and chlorine-37, but they are not stable. The unstable isotopes can convert to a more stable combination of neutrons and protons, and they do so according to a systematic pattern in time. These other isotopes of chlorine are said to be **radioactive**. Understanding why certain elements are radioactive requires a deeper understanding of the structure of the nucleus. Scientists are still trying to fully understand stability of the elements.

If the nucleus of an atom is too large, the protons on one side of the nucleus are too far away to attract the protons on the other side of the nucleus. The protons can still repel one another since the coulomb electrostatic force is long-range. The interaction between the repulsive electrostatic force and the attractive nuclear force is one determining factor on the maximum size of a nucleus.

The stability of an atom varies with the elements. Light elements become more stable as the atomic mass (the number of nucleons) increases. The most stable element is iron (atomic number 26) with an atomic mass of 56. Elements with larger atomic masses become less stable.

In general, elements with nuclear mass much, much less than 56 can combine to gain mass, become more stable, and give off energy. This process is called **fusion**. Elements with nuclear mass much, much greater than 56 can break apart to lose mass, become more stable, and give off energy. This process is called **fission**.

Fusion is the process of small nuclei combining to increase their mass. The best example of fusion processes is what occurs in the Sun and other stars. The fusion process is ideal for supplying safe energy because it releases very large amounts of energy without leaving much dangerous radioactive residue. However, it is very difficult to accomplish this on an industrial level at the present time. In the future we hope scientists will figure out how to harness the energy of nuclear fusion, because it would be an excellent source of energy for society.

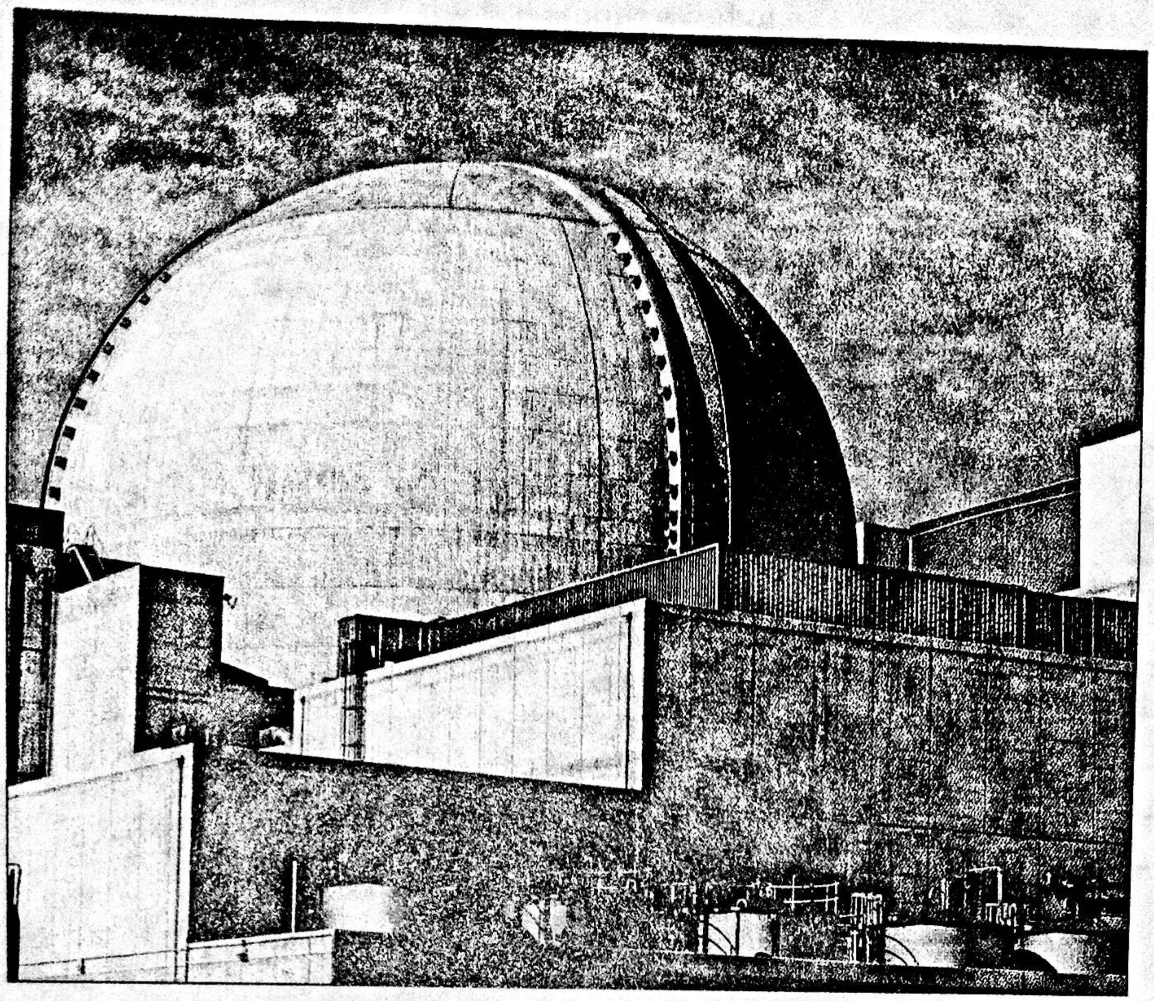
The process of splitting an atom into smaller atoms is called fission. This is the process that is used to produce nuclear energy. It is used to power nuclear submarines and to produce electrical energy in nuclear power plants all over the world.

Chem Words

radioactive: an atom that has an unstable nuclei and will emit alpha, positron, or beta particles in order to achieve more stable nuclei.

fusion: nuclei of lighter atoms combining to form nuclei with greater mass and release of a large amount of energy.

fission: the process of breaking apart nuclei into smaller nuclei and with the release of a large amount of energy.



The use of nuclear energy for the production of electricity is quite apparent as you look at the numerous states that depend on nuclear energy. For example, over 40% of Illinois' electricity is produced by nuclear energy. Nuclear fission does create some major problems: (1) Security, (2) Radiation, (3) Removal of spent rods, and (4) Disposal of waste. With these problems, there is a need for continued research. Numerous universities and government facilities are trying to improve the efficiency of nuclear fission and at the same time, trying to develop nuclear fusion for commercial use.

This ongoing research is expensive and depends on the government, industry, and other organizations to continue supporting this research. If we can learn how to harness nuclear fusion we can alleviate our nation's electrical problems while decreasing pollution. The field of nuclear science is going to continue to grow and the future will provide great opportunities for a young scientist like you to get involved.